Vascular Anatomy of the Spinal Cord and Classification of Spinal Arteriovenous Malformations

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Summary

The arterial and venous anatomy of the spinal cord was described in terms of extrinsic and intrinsic contribution to the cord substance. Based upon anatomical location of an arteriovenous shunt, spinal arteriovenous malformations (AVMs) were classified into intramedullary AVM, perimedullary arteriovenous fistula (AVF) and dural AVF. This simple classification seems practical from the standpoint of endovascular and surgical treatments since it reflects anatomical differences in the shunt location, which is the target in either approach.

Introduction

Although the terminology of the vessels supplying and draining the spinal cord is not always uniform, the vascular anatomy of the spinal cord has been well investigated regarding the anatomical location and function [1-6]. Because of the complex anatomy of the spinal arteriovenous malformations (AVMs), various authors have used different classifications of the spinal AVM; based upon the morphology of the lesion and the relationship of the lesion to the spinal compartments [7-11].

In this review article, we describe the vascular anatomy of the spinal cord and a simple classification of the spinal AVM.

Arterial Anatomy of the Spinal Cord

The arterial anatomy is schematically shown in figure 1. The arterial supply to the structures in the spinal canal is derived from two main sources, the vertebro-subclavian arteries and the thoraco-abdominal aorta, and occasionally from the internal iliac arteries as well [1]. Each segmental artery arising from these vessels gives rise to the dorsospinal branch, the spinal artery.

The spinal artery divides into ventral, middle and dorsal branches in the interverebral foramen. The ventral and dorsal branches distribute to the anterior and posterior part of the spinal canal to supply the dura mater and vertebral bone. The middle branch supplies the dura mater adjacent to the intervertebral foramen and it bifurcates to join the anterior and posterior nerve roots, becoming radicular, radiculopial or radiculomedullary arteries [1,6].

The radicular artery is short but exists at all segmental levels. The radiculopial artery represents large radicular arteries to reach the surface of the spinal cord. The radiculomedullary artery represents the arteries that contribute to supply the spinal cord over several spinal segments (the radiculomedullary artery may be called the radicular artery inclusively [2] or the medulary artery [10,12]).

The extrinsic arterial supply to the spinal cord derives from the anterior spinal artery, the

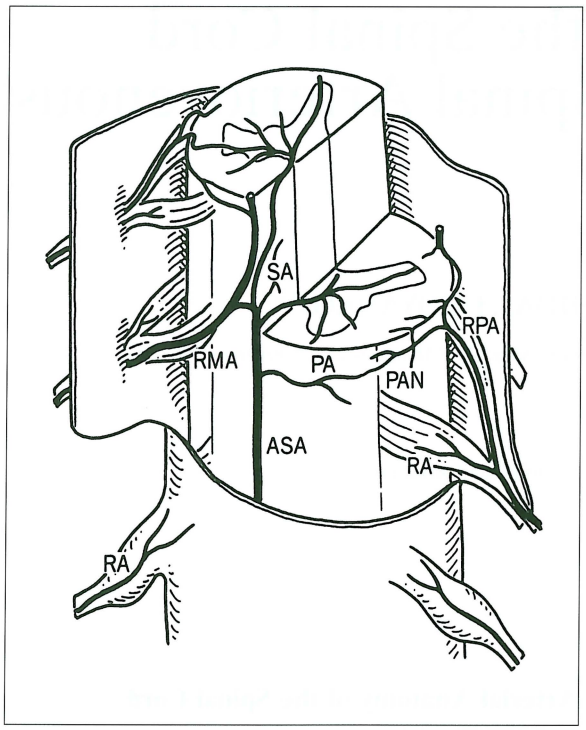

Figure 1 Schematic drawing of the arterial supply to the spinal cord. ASA, anterior spinal artery; PA, pial artery; PAN, pial arterial network; PSA, posterior spinal artery; RA, radicular artery; RPA, radiculopial artery; RMA, radiculomedullary artery; SA, sulcul artery.

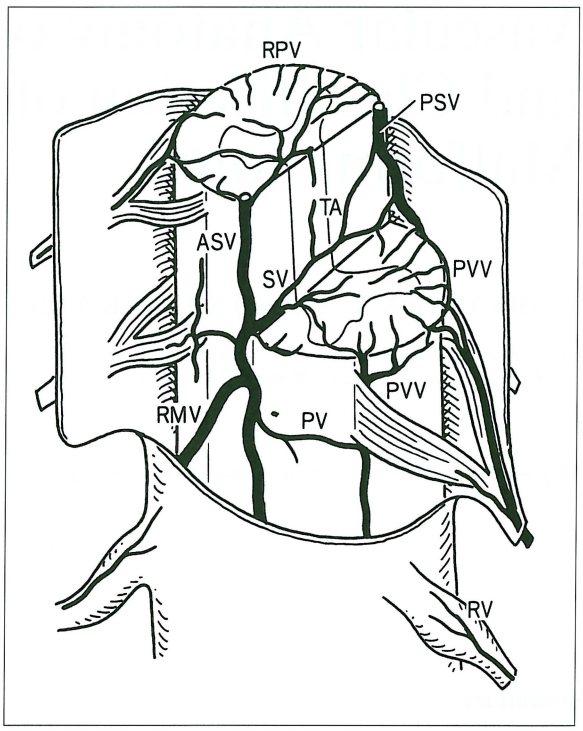

Figure 2 Schematic drawing of the venous drainage of the spinal cord. ASV, anterior spinal vein; SV, sulcul vein; PSV, posterior spinal vein; PV, pial vein; PVN, pial venous network; RPV, radial perforating vein; TA, transmedullary anastomosis; RV, radicular vein; RMV, radiculomedullary vein.

posterior spinal artery and the pial network. The anterior spinal artery receives radiculomedullary arterial contribution, while the posterior spinal artery and the pial network receive radiculopial arterial contribution. The anterior spinal artery is a longitudinal anterior axis from the basilar artery to the filum terminale. It may remain unfused, to be duplicated. Caudally it anastomoses with the posterior spinal artery to constitute an arterial arch. The anterior spinal artery lies on the midline beneath the pial coverage. It gives rise to many sulcul arteries into the anterior median sulcus, and the lateral branches coursing subpially over the anterior and lateral surface of the spinal cord [5]. The posterior spinal arteries come from the distal vertebral artery, occasionally from the posterior inferior cerebellar artery. They ran along the posterolateral surface of the spinal cord to the conus medullaris.

The posterior spinal arteries are situated on the posterior pial surface in the subarachnoid space [5]. The pial plexus, a wide-meshed network on the surface of the spinal cord, is formed with circumferential branches from the anterior and posterior spinal arteries. An additional supply is derived from the other radiculopial arteries.

The intrinsic arteries of the spinal cord consist of the central sulcal arteries and the peripheral radial arteries [2]. The sulcul arteries travel in the anterior median sulcus, and enter either the left or the right half of the spinal cord. Before penetrating the cord substance, they give rise to ascending and descending branches that anastomose with adjacent sulcal arteries on the same side [6]. The sulcul arteries centrifugally supply all of the anterior gray matter, the anterior part of the posterior gray matter, and the inner half of the white column. The radial perforating arteries originate from the posterior spinal arteries and the pial plexus, and penetrate the white matter. These centripetal arteries supply the posterior part of the posterior gray matter and the outer half of the white column.

Venous Anatomy of the Spinal Cord

The venous anatomy is schematically shown in figure 2. The intrinsic venous system of the spinal cord is radially and symmetrically arranged with axial anstomoses. The radial perforating veins distribute almost equally in the whole spinal cord and connect to a pial venous network on the surface of the spinal cord. The anterior sulcul vein runs ventrally in the anterior median sulcus, and drains into the anterior spinal vein.

The posterior sulcul vein directs posteriorly in the posterior median sulcus to drain into the posterior spinal vein.

The extrinsic venous drainage of the spinal cord consists of the pial venous plexus, and the anterior and posterior spinal veins. The pial venous plexus, the coronal venous plexus, represents a longitudinally and axially anasomosed network on the surface of the spinal cord. The anterior and posterior spinal veins are located at the midline on the ventral and dorsal aspects of the spinal cord respectively. The anterior spinal vein is situated subpially and slightly posterior to the anterior spinal artery. The posterior spinal vein may be a single channel at the midline; or, it may be duplicated or triplicated on the posterolateral aspect. These veins are situated on the posterior pial surface in the subarachnoid space. Unlike the arteries, there is no predominant pattern in terms of anterior and posteriosr venous drainage of the spinal cord.

The venous drainage of the structures in the spinal canal is done in a reverse fashion to the arteries.

The superficial veins surrounding the spinal cord are drained by radiculomedullary vein (radiculomedullary vein may be called "medullary vein"[3] or "radicular vein"[6]). In contrast to the arteries, these veins do not always exit the dural tube with the nerve roots[4]. In the intervertebral foramen, the radiculomedullary and radicular veins join the epidural veins (the internal vertebral plexus), which have the segmental communications with external vertebral plexus[4].

The external vertebral plexus eventually joins the caval system; mainly the innominate veins at the cervical level, the azygos vein at thoracic level and the ascending lumbar vein at lumbar level[6].

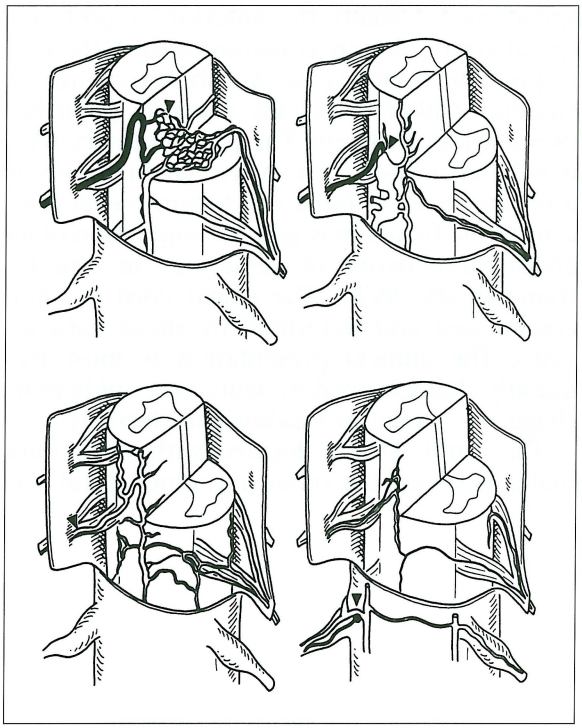

Figure 3 Types of spinal AVMs. Intradual AVM (upper row) consists of the intramedullary AVM (left) and perimedullary AVF (right). Dural AVF (lower row) presents with intradural drainage (left) or extradural drainage (right). The site of A-V shunt is indicated by an arrow head.

Classification of Spinal Arteriovenous Malformations

Spinal arteriovenous malformations (AVMs) are simply classified into intramedullary AVM, perimedullary arteriovenous fistula (AVF) and dural AVF (figure 3). The classification is based upon anatomical differences in location of the arteriovenous shunt in relation to the spinal cord and dural tube.

The intramedullary AVM always have feeders from the anterior spinal artery and its branches, and simultaneously it is frequently fed by posterior spinal artery. The lesion usually drains into both anterior and posterior spinal veins. These AVMs may have a nidus but may not be completely buried in the cord parenchyma; they may remain outside the spinal cord in the anterior median sulcus. A venous varix may be associated with intramedullary AVM. The most striking clinical symptom of this type is hemorrhage.

The perimedullary AVF is the shunt between a pial artery and vein, presenting outside the

spinal cord. Usually the anterior or posterior spinal artery directly communicates to the corresponding spinal veins. An abrupt change of vascular caliber marks the shunting point between artery and vein. The perimedullary AVF may be associated with an arterial aneurysm or a venous varix. Dilated and tortous veins adjacent to the fistula may give an impression of an abnormal network of vessels as in an intramedullary AVM. The spinal cord is often compressed and deformed by those varicous veins. The clinical presentation is most frequently characterized by acute onset of hemorrhage, but it may be insidious myelopathy.

The dural AVF is located within the dura mater between the outer and inner dural layers, usually close to the nerve root at the intervertebral foramen. The lesions are direct AVFs that link the dural branch of the radicular artery with the radiculomedullary vein [12]. Dilated and tortous veins run on the surface of the spinal cord over a long distance. The retrograde flow of shunted blood results in venous congestion in the spinal cord, eventually to provoke progressive myelopathy. Venous outflow of the AVF occasionally directs to the epidural veins but not to the radiculomedullary veins [13].

Metameric AVMs may be associated with a vertebral, menigeal or medullary vascular lesions. We simplify their classification to the one that includes dural AVF, perimedullary AVF and intramedullary AVM.

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